Role of clouds, aerosols, and aerosol-cloud interaction in 20th century simulations with GISS ModelE2

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Introduction

The key uncertainties in the climate sensitivity to the increasing greenhouse gases lie in the behavior and impact of short-lived species, such as tropospheric aerosols and ozone, and secondly, in the response and impact of the ocean circulation.

Model and experiment descriptions

We use the new version of NASA GISS climate model, modelE2 [*Schmidt et al.,* 2014]. We use two different treatments of the atmospheric composition and aerosol indirect effect: (1) TCAD(I) version has fully interactive Tracers of Aerosols and Chemistry for total aerosol number and mass concentrations in both the troposphere and stratosphere [*Shindell et al*., 2013]; (2) TCAM is the aerosol microphysics and chemistry model [*Bauer et al.*, 2008]. Both TCADI and TCAM models include the first indirect effect of aerosols on clouds [*Menon et al*., 2010]; the TCAD model includes only the direct aerosol effect.

We consider the results of the TCAD, TCADI and TCAM models coupled to "Russell ocean model" [*Russell et al.*, 1995], E2-R.

We examine the climate response, the effect of clouds, their feedbacks, and the aerosol-cloud interactions for the "historical period" that include the natural and anthropogenic forcings for 1850 to 2012.

Results

Simulated global mean total mass of sulfate, nitrate, organic carbon, black carbon, sea salt and dust are presented in Figure 1 as a time-series of anomalies relative to the year 1850 values. The evolutions of aerosol total masses follow specified time-varying emissions with differences between the mass-based and microphysical aerosol models.

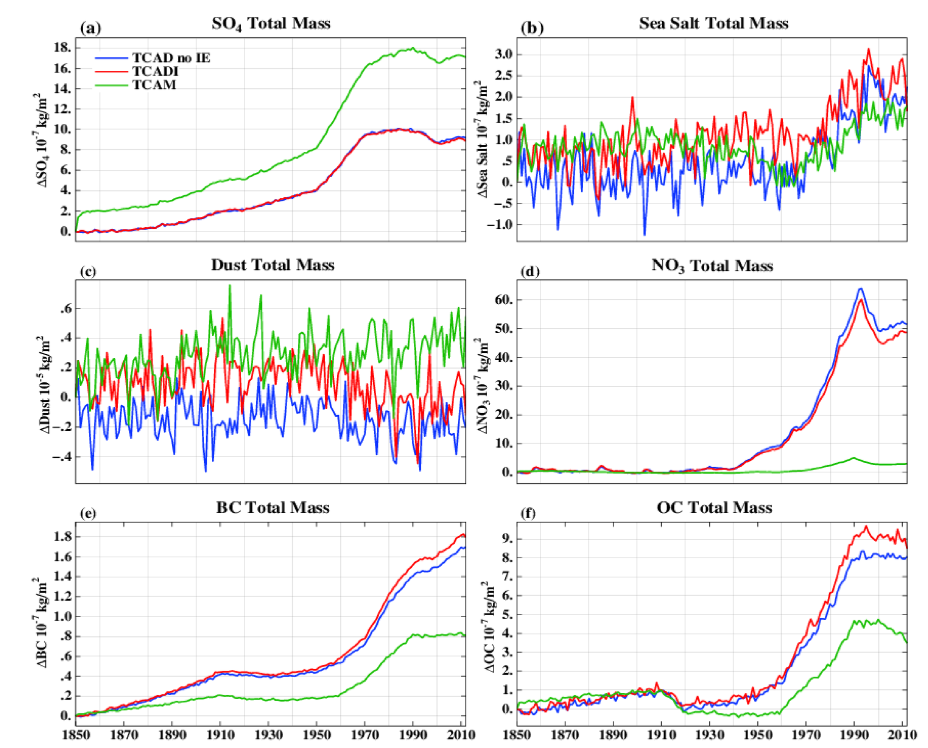

Fig. 1. Anomalies relative to 1850: (a) sulfates; (b) sea salt; (c) dust; (d) nitrates; (e) black carbon; (f) organic carbon.

The change of SAT between 1880 and 2012 based on linear trend ranges between +0.8°C and +1.2°C (Fig. 2a), which agrees with the observed temperature increase estimated as 0.9°C. The largest warming is simulated in the TCAM model globally, in the Northern and Southern Hemispheres, and over the land and ocean surfaces. The smallest warming is in the TCADI model. Clouds become optically thicker with increasing temperatures (Fig. 2b).

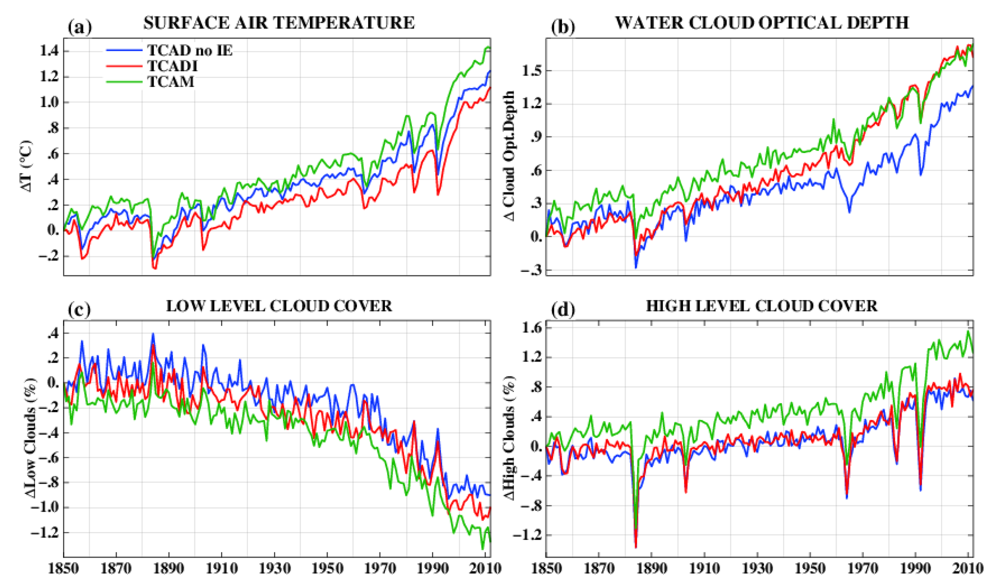

Fig. 2. Anomalies relative to 1850: (a) global annual mean surface air temperature; (b) water cloud optical depth; (c) low level cloud cover; (d) high level cloud cover .

The largest warming in the TCAM model is accompanied by the largest decrease of the low level clouds (Fig. 2c) and the largest increase of the high level clouds (Fig. 2d) compared to the other two models.

Due to stronger warming in the TCAM model, the liquid water content of clouds shows strong increase despite the fact that low level cloud cover reduced. The increase of the liquid water content in clouds is pronounced over the ocean due to more evaporation from the surface. The ice water content in the TCAM model increased the largest of the three models as the result of the more high level clouds in this model.

The TCADI model produces larger increase of the large scale CDNC for tropical and sub-tropical low and middle level clouds between the present day and the pre-industrial times (Fig. 3a). The smaller change of CDNC in the TCAM model is reflected in larger size of the cloud particles (Fig. 3b).

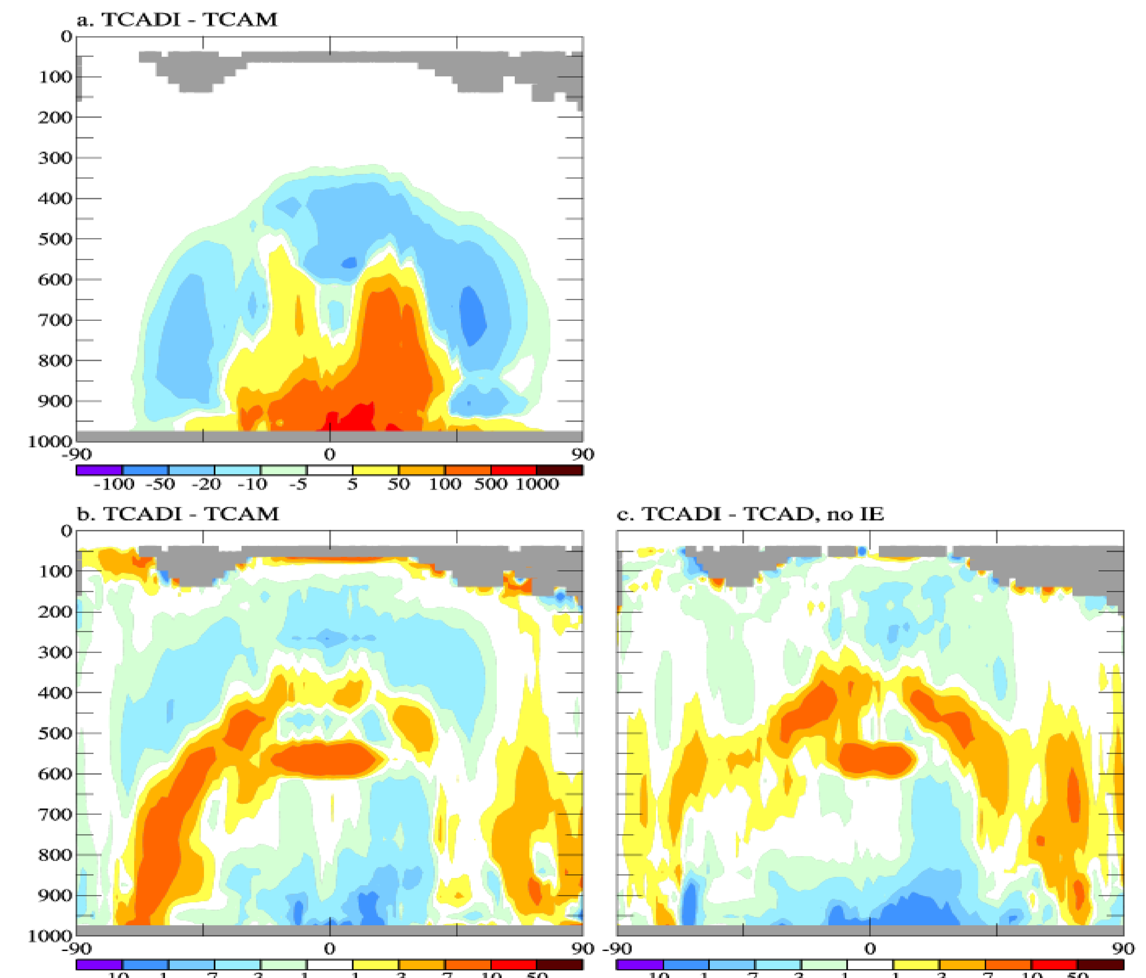

Fig. 3. The change of annual means (2003-2012) and (1850-1859) for (a) large-scale cloud CDNC (cm^{-3}), TCADI-TCAM; (b) large-scale cloud particle size (micron), TCADI-TCAM; (c) the same as b but for TCADI-TCAD.

The TCADI model simulates optically thicker water clouds over low latitudes (Fig. 4a). Over the Southern Ocean and over the high and middle northern latitudes, the water clouds are optically thicker in the TCAM model due to larger increase of liquid water content in this model (Fig. 4b).

Since there is no indirect effect parameterization is included to the TCAD model, the larger size cloud particles are simulated for the present day aerosol loaded atmosphere in this model compared to the TCADI model (Fig. 3c). As a result of it, the clouds are optically thinner in the TCAD model (Fig. 4c) consistent with the change of the global mean water cloud optical depth (Fig. 2b).

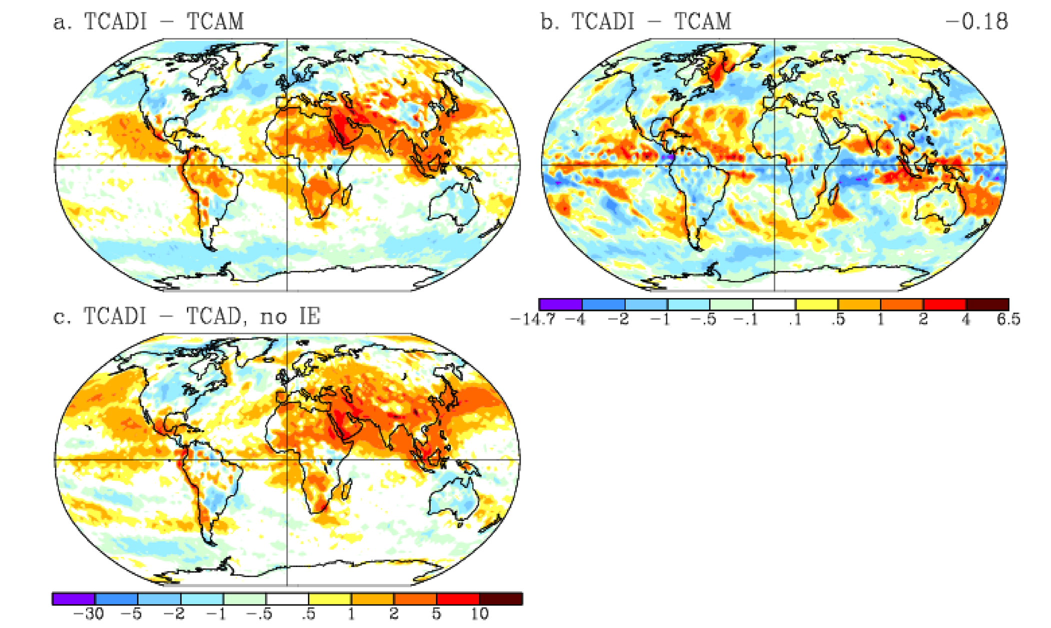

Fig. 4. The change of annual means (2003-2012) and (1850-1859) for (a) water cloud optical depth, TCADI-TCAM; (b) liquid water path (10^{-2} kg/m^2), TCADI-TCAM; (c) the same as b but for TCADI-TCAD.

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